

COMPUTER AIDED ANALYSIS OF IMMEDIATE AIR-SUPPORT OPERATION

**A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY**

By

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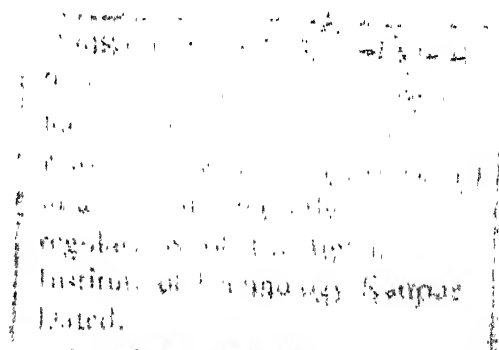
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ABSTRACT

'Systems Analysis' is described as the application of scientific method to problems of economic choice. Its objectives is primarily to recommend a course of action or policy, rather than merely to understand and predict. However, 'military systems analysis' differs from ordinary systems analysis in its enormous responsibility, in sometimes being forced by the nature or urgency of a problem to substitute intuition for verifiable knowledge.

This idea of an analysis to provide advice is not new and, in concept what needs to be done is simple. The approach is to construct and operate within a model. Such a model, which may range from an elaborate computer program to a war game played on a sand model, enable the participants in the study to make their judgements in a concrete context.

Analysis of a hypothetical immediate air-support operation has been attempted on DEC-1090 computer system. Courses of action suggested by this analysis have been validated by taking situations in which there are obvious results which are based on military experience.

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A word of thanks to Mr. M.C. Gupta for his neat typing.

A handwritten signature in cursive script, reading 'Mantani', with a horizontal line underneath.

(Capt. D.C.R. Mantani)

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CHAPTER I

OVERVIEW

1.1 INTRODUCTION

Few activities of mankind are more complex than combat operations, and few have been studied as assiduously. During the desperate military situation that arose in England during the Second World War, it occurred to the people responsible for defence of that country that physicists, biologists, mathematicians, and other trained people might have something to contribute to what were almost universally considered strictly military problems. This, ultimately resulted in forming the beginning of a body of knowledge called at that time 'Operations Research' and later as 'Systems Analysis' by RAND Corporation.

Various techniques like gaming and simulation were developed to help in analysing complex situations that came up during military operations. The success of Operations Research is a well established fact now.

1.2 Need for systems analysis:

Initially, OR was primarily used to solve logistics problems and carry out cost-effectiveness studies. Later need arose to use it in analysing real

combat situations. In a combat situation, which inherently introduces uncertainties and complexities, the need for arriving at the right decision is a must. Due to the complexity of weapons and their greater damaging power, some form of systematic analysis of the combat situation would help a commander greatly to choose the right course of action.

Reaction time or time available to make a decision is reducing day by day due to enhanced mobility in modern warfare, thereby, increasing the need for some aid in decision making for the commander. This would help to avoid the wrong decisions that may be made under the stress of time.

Courses of action suggested by systems analysis are unbiased and their utility depends largely on the data fed. These alternative can be put down in a presentable and simple form to the commander so as to help him make a quick decision.

1.3 Development of analysis using the digital computer:

Keeping the above needs in mind, analysis of a hypothetical combat operation of immediate air support to

ground forces has been attempted. Two techniques of systems analysis, namely, 'simulation' and 'theory of games of strategy' have been used to simulate and analyse the combat situation on the Dec-1090 computer.

Some of the difficulties encountered were, lack of relevant literature and data. The authenticity of the results of analysis could only be checked with the help of military experience. Only extreme situations with obvious results have been analysed and compared with results obtained from the analysis developed, thereby partly validating the analysis.

1.4 Overview of the Thesis:

The aim of this thesis is three fold: firstly to carry out the simulation of the hypothetical combat situation which involves simulating the terrain on the computer and reducing the data so that it lends itself to analysis; secondly, to carry out analysis of the simulated model using game theory concepts and thirdly, to solve the problem of immediate air support for army.

Chapter 2 gives briefly a general introduction to 'systems analysis' and its techniques. In chapter 3 the chosen combat situation is elaborate. This chapter

also deals with the logic and form of the analysis developed. Chapter 4 deals with development of simulation and calculation of combat effectiveness. In chapter 5 the game matrix is developed and analysed. The results are compared with results evaluated on the basis of military experience, and conclusions drawn in chapter 6.

CHAPTER II

SYSTEMS ANALYSIS AND TECHNIQUES

2.1 Definition: The idea of using analytic techniques to the problems of military operations evolved in a major way during world war II. It proved to be highly successful. Major boost to this activity was provided by the introduction of new weapon systems, novel in concept and design, whose exploitation could not be planned purely on the basis of traditional military experience. This warranted search for new methods of analysis which ultimately came to be known as 'Systems Analysis'.

What is systems analysis? Systems analysis [QB-1] is not a method or technique, nor is it a fixed set of techniques. It takes its character largely from the problem it addresses to. Techniques used differ from study to study.

Properly speaking, it is a research strategy, a practical philosophy of how best to aid a decision maker with complex problem of choice under uncertainty. Systems analysis can be characterised as a systematic approach to help a decision maker choose a course of action by investigating his full problem, searching out objectives and alternatives, by comparing them in an appropriate framework to bring expert judgement and intuition to bear on the problem.

2.2 Applications of system analysis:

Analytic techniques can be applied to military

problems which range from routine day-by-day operations of the services to critical one time decision of military operations. This spectrum may be divided into the following categories [QB-1]:

- (a) Management of operations.
- (b) Choice of tactical alternatives.
- (c) Design and development of weapon systems.
- (d) Determination of major policy alternatives.

In the first category, analysis takes its most mathematical form. This kind of analysis is no different from analysis done to support decision making and resources allocation in commerce and industry. It is management science or operations research in the strict sense-an attempt to increase efficiency in various operations of the military establishments.

Analysis in the remaining three categories involves the element of conflict. In true conflict situations it is the interactions with the enemy, that is likely to be the main problem.

In combat analysis, the situation sometimes can be represented by means of mathematical models with such realism that the theory of games proves useful.

2.3 Techniques available to the Military Analyst:

Among the various techniques for studying combat situations available to the 'Military Engineer', are the

following:-

- (a) Simulation
- (b) Operational gaming
- (c) Theory of games of strategy

2.4 Simulation:

It is a technique [QB-1] which is extensively used by Military analysts for studying complex military processes. It consists of an abstract representation of the more important features of the situation to be studied, designed to be played through in time, either by hand or by computer.

Most military simulations exhibit a common structure which can be expressed in terms of:-

- (a) Elements
- (b) Attributes
- (c) Activities
- (d) Plans
- (e) Time

'Elements' are all the items involved in the interaction such as missiles, tanks and troops. 'Attributes' are the properties of the elements-location, speed, type and so on. 'Activities' are the rules prescribing what will occur under various circumstances. 'Plans' are the prescriptions of how weapons are to be employed-strategy, tactics, doctrine etc.

Military conflict is a dynamic interaction of destructive events, where the relative time of an occurrence can be crucial. There are two ways of handling time in a

simulation: the interval and event techniques. There are two techniques for handling chance events as most military events are partially determined by chance. These are the expected value and Monte-Carlo methods.

Generally, simulation deals with effectiveness computation and forms part of overall systems analysis. Advantages of simulation are that it can analyse a highly complex combat situation by reducing it to more elementary form. In this way hypothetical future conflicts can be studied. On the negative side, simulation is likely to be a slow and cumbersome method. Also the question, 'How do we know that a simulation actually represents what it is supposed to?' is not easy to answer. It is difficult to determine how good a simulation is. The ultimate test might appear to be a war of the type being simulated. But even if such a war were to occur the outcome might look quite different from outcome of the simulation and yet the simulation might not be wrong.

2.5 Operational Gaming:

Many important military problems were studied by a technique called 'Operational Gaming' [AH-2]. The military service defines a war game as a simulation, by whatever means, of a military operation involving two or more opposing forces, using rules and procedures, designed to depict an actual or assumed real life situation.

Operational Gaming or war games are employed to serve

three purposes:-

- (1) Gaming to train military personnel
- (2) Gaming to test plans
- (3) Gaming for research

Rudiments of war games: Though war games differ in many respects from one another, certain basic characteristics are present in all. Among the salient similarities are:-

- (1) Every war game simulates a military operation
- (2) Each game involves two or more opposing forces
- (3) Each war game is conducted in accordance with procedures acceptable to the military.
- (4) Every war game represents an actual or assumed real life situation

An activity cannot be termed as war game unless forces are involved in movements or operations accompanied by the clash of arms or the threat of such a clash. War games are played only under conditions of simulated warfare.

There are various limitations of war gaming. The study of war may never become an exact science because of inability to predict human action and reaction. A major limitation is the inability to quantify data like state of training, fatigue, courage, morale etc. which all wield considerable influence on the outcome. Even the effects of measurable forces like fire power, rate of fire, lethal area on the troops in battle are not fully known.

2.6 Theory of Games of strategy:

Games of chance have been studied mathematically

for many years: the mathematical theory of probability was developed from their study. The first attempt to express an abstract strategic situation into a mathematical theory of strategy was made by Emile Borel in 1921 [MD-3]. The theory was firmly established by John Von neumann in 1928 when he proved the mini-max theorem which is the fundamental theorem of games of strategy.

The theory of games of strategy is a mathematical treatment of planning or decision-making under conditions of conflict. The theory is concerned with the selection of an optimal course of action taking into account not only the possible actions of the own side but those of the enemy as well.

This theory considers the problem of how a participant in a conflict situation can obtain the largest pay-off under conditions such as:-

- (a) The opponents will attempt to discover each others strategy and at the same time conceal their own.
- (b) Each participant has only partial control over the outcome.
- (c) Each opponent may bluff or feint.
- (d) The opponents have different amounts of information or intelligence about each other.
- (e) The participants may be constrained by the elements of chance.

Description of a game of strategy:

A game of strategy is described by its set of rules. It distinguishes between games involving two players and games involving more than two players. Two person game can be further

classified as zero sum games and non-zero sum games. In zero-sum games what one player wins, the other necessarily loses.

Concept of strategy is used in games of strategy. Strategy of a player is a set of instructions for playing a given game from the first move to the last.

With the concept of strategy in mind we can describe a game between two players, say Blue and Red. Blue has m strategies and Red has n strategies. The Blue's payoff matrix is given by $[a_{ij}]$ which means if Blue chooses the i th strategy and Red chooses the j th strategy the payoff for Blue would be a_{ij} .

The game is thus determined by Blue's payoff matrix:-

$$A = \begin{bmatrix} a_{11} & a_{12} & \text{-----} & a_{1n} \\ a_{21} & a_{22} & \text{-----} & a_{2n} \\ \vdots & & & \\ a_{m1} & a_{m2} & \text{-----} & a_{mn} \end{bmatrix}$$

The effort of Blue would be to make a_{ij} as large as possible but he controls only the choice of his strategy i . Whereas Red would want to keep a_{ij} as low as possible but he controls only the choice of his strategy j .

Now for any strategy i which Blue chooses he can be sure of getting at least

$$\min_{j \leq n} a_{ij}$$

where minimum is taken over all of Red's strategies. Blue is at liberty to choose i ; therefore, he can make his choice of i in such a way as to ensure that he gets at least

$$\max_{i \leq m} \min_{j \leq n} a_{ij}$$

similarly Red can make his choice of j so that Blue would get at most:

$$\min_{j \leq n} \max_{i \leq m} a_{ij}$$

In general, these quantities are different, but satisfy the relationship

$$\max_{i \leq m} \min_{j \leq n} a_{ij} \leq \min_{j \leq n} \max_{i \leq m} a_{ij}$$

This inequality is proved as follows: Given any i then

$$\min_{j \leq n} a_{ij} \leq a_{ij} \quad \text{for all } j$$

Given any j , then

$$\max_{i \leq m} a_{ij} \geq a_{ij} \quad \text{for all } i$$

Hence we have

$$\min_{j \leq n} a_{ij} \leq a_{ij} \leq \max_{i \leq m} a_{ij}$$

or

$$\min_{j \leq n} a_{ij} \leq \max_{i \leq m} a_{ij}$$

Since right hand side of the preceding inequality is independent of i , we have by taking maximum of both sides

$$\max_{i \leq m} \min_{j \leq n} a_{ij} \leq \max_{i \leq m} a_{ij}$$

Now the left hand side of preceding inequality is independent of j . By taking the minimum of both sides, we have

$$\max_{i \leq m} \min_{j \leq n} a_{ij} \leq \min_{j \leq n} \max_{i \leq m} a_{ij}$$

A critical point in game theory so far as its application to real-life conflict situations is concerned, is reached when we try to evaluate the values of pay off. In general we have to assume that the payoff can, in principle, be measured numerically. One conceptual difficulty [JDW-4] in connection with real problems is that of defining the problem clearly, so that the action alternatives available to the players may be completely itemized; and to do this without isolating the problem from the important influence of its original environment.

CHAPTER III

DESCRIPTION OF PROBLEM AND FORM OF PROPOSED ANALYSIS

3.1 Scenario of the Problem

In a theatre of war the battle usually develops along many fronts. In an event of an attack, the enemy tries to conceal his main thrust, by attacking along a number of places simultaneously. This way, he tries to distribute the defensive capabilities of his opponents, thereby increasing his probability of success and maintaining surprise about his intentions or aims.

In such a situation, it so happens that a number of field units of own forces may raise demand for air support at the same or around the same time. Procedures have been developed wherein the air-support demands get scrutinized by intermediate HQs and ultimately reach the Corps HQs. Corps HQs is the place where both representatives of army and air-force, process such demands and finally issue orders to the air bases to carry out the air-support missions.

The problems of officials at this Joint Operation Centre (JOC) is to evaluate whether a demand warrants an air strike and its priority. The air power in modern warfare is always at a premium and it is essential that a right decision is made at JOC.

3.2 Existing System

The Corps HQ is the lowest formation HQ where there exists direct liason between the army and the air force. The

JOC forms the nerve centre of all ground support operations. The system organisation is shown in Fig. (3.1)

In an event, when the requirement of air-support is raised by a unit, the demand travels through normal channels till it reaches JOC. The demands raised by various units are processed and evaluated at JOC, based on the factors mentioned below:-

- (a) Enemy's intention
- (b) Own future plans
- (c) Deployment of own and enemy's forces
- (d) Vulnerability of a particular sector
- (e) Air situation
- (f) Tactical soundness
- (g) Terrain evaluation
- (h) Intelligence reports

Data is collected from various sources like forward troops, POWs etc. and conclusions drawn from them are represented on a map. The commander appreciates the situation off the map and arrives at a decision. The soundness of this decision depends upon commander's experience and reliability of data collected.

This in brief is the procedure followed from the initiation of demand till its execution. Before proceeding with the proposed analysis, the following assumptions are made.

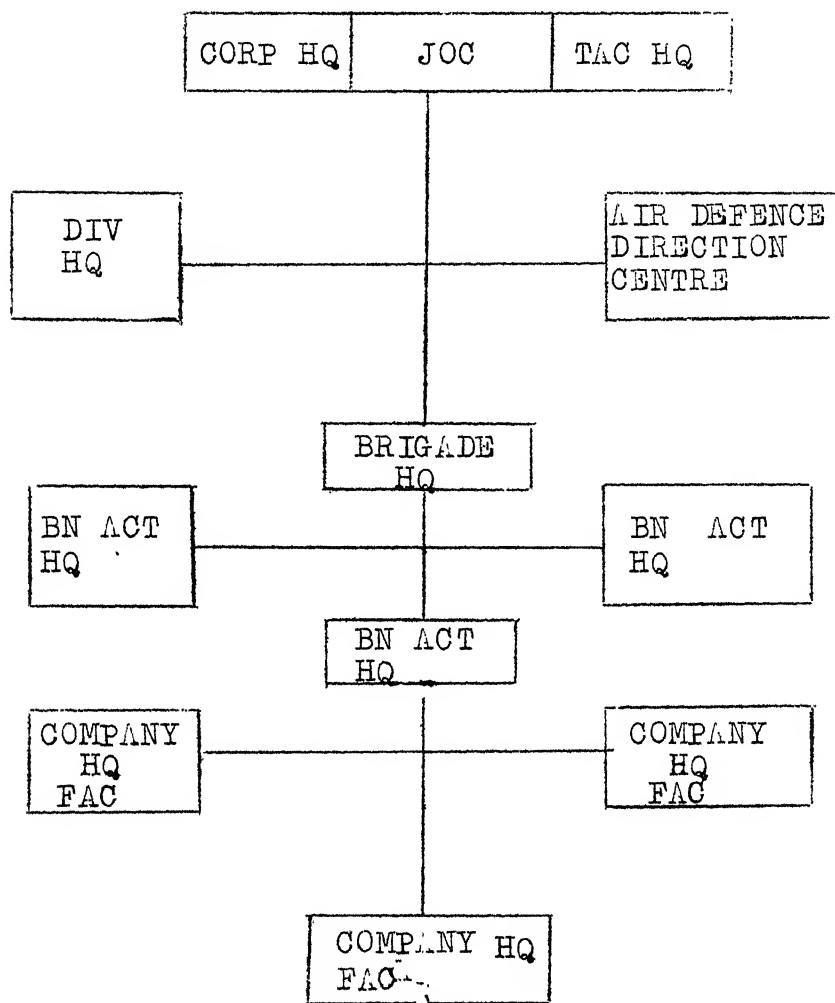
ORGANISATION CHART FOR JOINT AIR/LAND WARFARE

Figure No. (3.1)

3.3 Assumptions:

- (a) The terrain of operation is hypothetical but has characteristics similar to the terrain of Punjab.
- (b) For the purpose of identification own forces are represented as BLUE force and enemy as RED force.
- (c) The enemy is considered to be rational, clever and to act in a manner by which he benefits
- (d) Hypothetical data about RED and BLUE forces has been used.
- (e) Adequate intelligence information of RED force is available with BLUE force and vice-versa.
- (f) Analysis assumes conventional warfare.

3.4 Development of Analysis

The present day 'detente' in the world is maintained because balance of force between two opposing forces is maintained. The defence analysts emphasize that this balance must be maintained in order to prevent war. In order to carry out analysis of the combat situation the above concept of 'balance of force' has been used. It is rational to assume that as long as there is balance of force maintained in a sector of battle, the enemy would not be tempted to attack.

To determine 'balance of force' some measure of combat-effectiveness of forces is required. It is logical to assume that all field units wield their influence in a certain area. All units whose influence is felt at a particular point, in this case the point of attack, would have some effect on the outcome of battle. The combat-effectiveness of a sector is the sum of effects of all such units at the point of attack. The difference between the combat effectiveness of Red and Blue forces at the point of attack would yield us the state of

balance of force at that point.

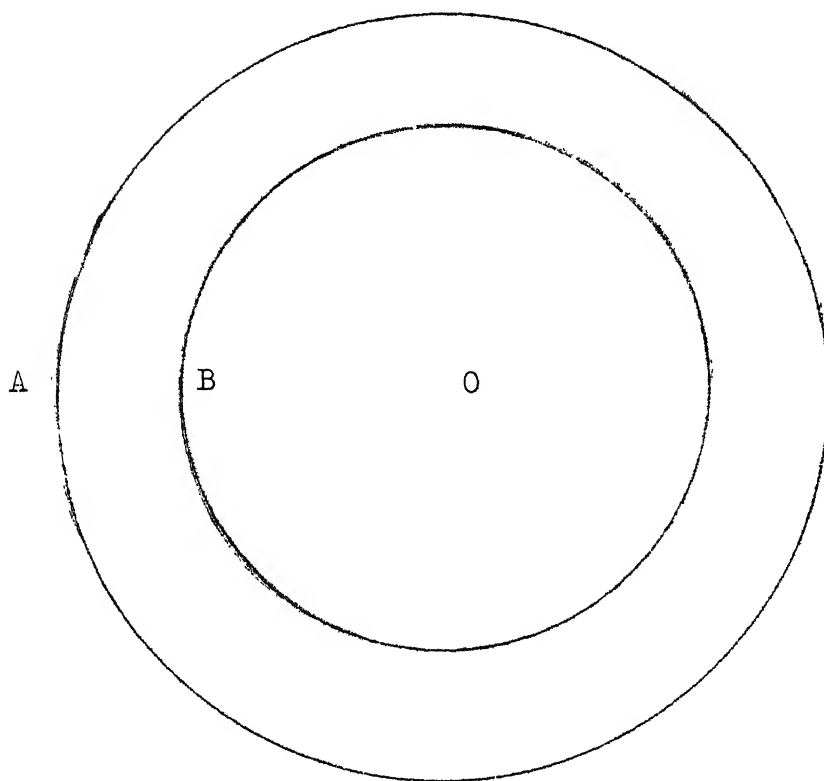
The immediate air support operation usually takes about $1\frac{1}{2}$ hrs. to 2 hrs. from the time of raising demand to its execution. Logically, all units that are capable of taking part in operation within this time duration can have effect over the outcome. For the purpose of this analysis, the area of influence for troops has been taken as a circle of 20 Kms. radius and area of influence for armour and artillery is taken as a circle of 30 Kms. radius. Refer Figure (3.2).

3.5 BLOCK DIAGRAM OF THE ANALYSIS

A block diagram of the analysis is given in Fig.(3.3). In first step the terrain is represented in a computer and the variable data of deployments of forces and air demands is fed in. In the next step combat-effectiveness calculations are made. Next, the game is defined and elements of game matrices are evaluated. These matrices are then solved and deductions based on the solutions are obtained. The analysis and relevant factors are represented in a form which helps the commander in making his decision.

3.6 Combat-effectiveness Calculations

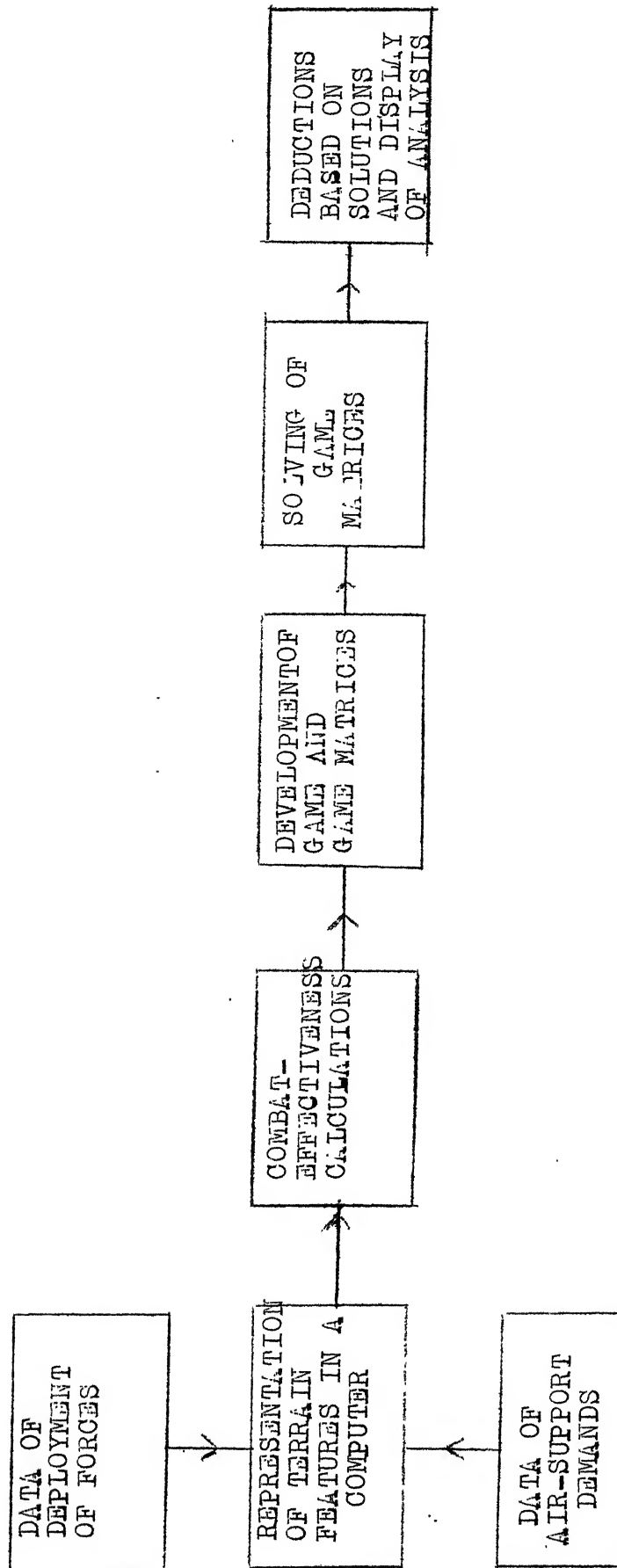
Let us begin by considering the concept of combat-effectiveness from an analytical point of view. Although there is no general definition of combat effectiveness, the question, 'Is the combat-effectiveness of unit A greater than that of unit B?' is meaningful and capable of being answered

CIRCLE OF INFLUENCES

The area of influence for troops is a circle of radius 20 Kms. as shown by circle whose centre is at O, i.e., point of attack and $BO = 20$ Kms.

The area of influence for armour and artillery is circle of radius 30 Kms. In the figure $AO = 30$ Kms. All units of armour and artillery are searched for within this circle.

Figure (3.2)



BLOCK DIAGRAM OF ANALYSIS

Figure No. (3.3)

by experienced military personnel if sufficient information about the two units is available. The situation is analogous to the one in which a rational consumer is asked to express a preference between two 'commodity bundles', each bundle consisting of various numbers and kinds of economic goods. In order to express a preference one must have a criteria by which one should judge the utility of the two bundles. Here utility is analogous to combat-effectiveness.

Index of combat-effectiveness (ICE) is the result of factors that may or may not lend themselves easily to quantification. For example, morale command and control, organisation, state of training etc. do not lend themselves easily to quantification. Such qualitative data has been quantified by means of scaling. For example, qualitative standards, such as 'outstanding', 'superior', 'good',, are assigned values 1.0, 0.9, 0.8.... and so on. These numerical values are used as multipliers of normal performance to upgrade or degrade expected performance.

The criteria used for judging combat effectiveness is the total fire-power available at a point. Success of any force is directly proportional to the amount of fire power it can generate.

3.7 Index of Combat Effectiveness (ICE) for troops:

I.C.E. for troops is defined as the capability of generating maximum fire power by a particular unit.

$$\begin{aligned}
 \text{I.C.E. for troops} &\propto \text{Fire power} \propto N \\
 &\propto R \\
 &\propto \left(1 - \frac{D}{K1}\right) \text{ for } D \leq K1 \\
 &\text{and } 0 \text{ for } D > K1
 \end{aligned}$$

where N is the number of combatants taking part

R is rate of fire of weapons

D is the distance of the unit from the point for which combat effectiveness is being calculated.

K1 is the maximum distance upto which combat-effectiveness of troops is felt.

[Refer Figure (3.4) for example]

Morale factor has been quantified by assigning a numerical value, which is used as multiplier in the calculations. These values would have to be assigned to each unit by its immediate superior commander and would be fed to JOC daily. Any changes would be updated by updating the file dealing with details of troops.

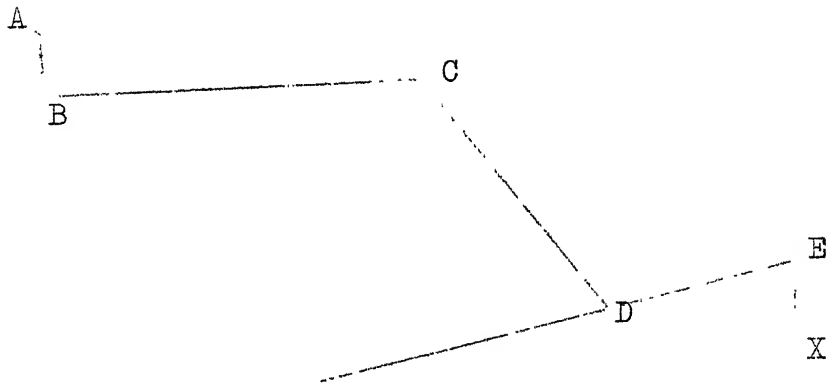
Numerically I.C.E. for troops is

$$= N \times R \times MF \times \left(1 - \frac{D}{K1}\right)$$

where MF is the morale factor multiplier. In the present study K1 has been chosen to be 20 Kms.

3.8 Index of Combat-Effectiveness for Armour:

Armour is a highly mobile war machine and can be deployed quickly by a commander with effective results.



A is location of troop unit with N troops

X is point of attack

Shortest distance between A and X is given by road branches AB, BC, CD, DE and EX.

Let this shortest distance be equal to D

I C E for troops is given by

$$= N \times R \times (1 - \frac{D}{Kl})$$

Kl is taken to be 20 Kms.

R is the rate of fire

Figure (3.4)

Normally, armour is used with infantry in an attack. The criterion for determining I.C.E. for armour units is the same as used for troops, i.e. maximum fire power it can generate thus

$$\begin{aligned} \text{I.C.E. for armour Fire power} &\propto N1 \\ &\propto R1 \\ &\propto LA \\ &\propto \text{Speed} \\ &\propto \text{Terrain} \\ &\propto \frac{1}{\text{Distance}} \end{aligned}$$

where N1 is number of tanks in the unit

R1 is rate of fire of main gun

LA is the lethal area of shell. i.e. area in which killing is 100%.

The speed dictates the size of circle of influence. For purpose of this analysis, all armour units within a radius of 30 Kms., are assumed to be capable of having influence over battle.

Terrain effects mobility of armour and therefore affects the time required to travel from one place to another. The terrain has been divided into various categories and have been allotted terrain factor. Terrain factor denotes the amount by which terrain would affect the mobility.

$$\begin{aligned} \text{I.C.E. of armour} \\ = N1 \times R1 \times LA \times \left(1 - \frac{D1}{K2}\right) \end{aligned}$$

where D1 is the shortest distance between armour unit and centre of circle of influence after taking into account the effect of terrain on mobility.

K2 is the maximum distance at which combat effectiveness of armour is felt. In this study it is taken to be 30 Kms.

[Refer Figure (3.5) for example]

3.9 I.C.E. of Artillery

Artillery is an arm which is generally used to soften targets before an attack. The I.C.E. of artillery is dependent upon

I.C.E. \propto N2
 \propto R2
 \propto range of guns
 \propto number of enemy troops it can bring under fire.

The range of the guns dictates the radius of circle of influence. It has been assumed to be 30 Kms.

The effectiveness of guns is also dependent upon the number of enemy troops it can bring under fire.

Numerically:

I.C.E. of artillery = $N2 \times R2 \times NET \times IA$

where N2 = No. of guns deployed

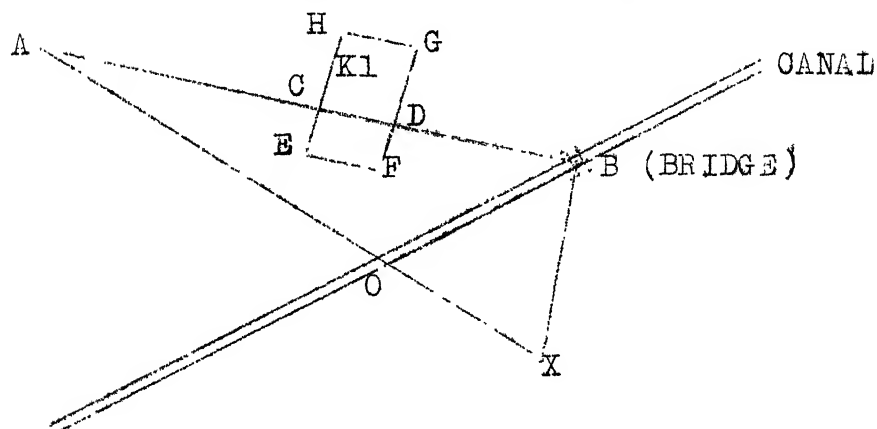
R2 = rate of fire (shells/min)

IA = lethal area of shells

NET = No. of enemy troops which can be brought under fire

3.10 Game Theory Analysis

After evaluating I.C.E. of Blue and Red forces at all points of attack, we proceed to define the game as:



In above figure location of armour unit is at A and centre of circle of influence is at X, i.e., point of attack. AX is the shortest distance from A to X. However, there is a canal in between and crossing point is at O. The nearest bridge from crossing is at B. Therefore route to be followed is AB, BX.

Route from A to B has to cross a terrain of classification K1 for distance CD.

Hence total distance to be traversed becomes

$$= AC + (CD \times K1) + DB + BX$$

This value of distance is used in I.C.E. calculation for armour.

Figure (3.5)

'Blue and Red are two forces with conflicting interests. Mission of Red is to attack Blue at a number of points with the intention of thrusting through Blue's defences at one of these points. The choice of point of main thrust is random in nature. Red's possible strategies are the choice of having his main thrust at any one of the points of attack. Strategies available to Blue are to provide air-support at any of these points.'

Assuming that there are three places where Red has attacked, there are nine possible outcomes which may be summarized by a 3x3 matrix. For example:

		<u>Blue</u>		
		1	2	3
Red	1	a_{11}	a_{12}	a_{13}
	2	a_{21}	a_{22}	a_{23}
	3	a_{31}	a_{32}	a_{33}

a_{ij} gives us the payoff to Red. Since we are analysing the above game as a two-person, zero sum game, the payoff to Blue is $-a_{ij}$. a_{ij} represent the payoff function as seen by the blue, evaluated by the information available with him, and need not be the actual payoff.

a_{ij} denotes what payoff is available to Red as seen by blue, if Red selects i th strategy and Blue selects j th strategy.

3.11 Evaluating Game Matrix:

In order to allot numerical quantities for elements of the game matrix, in case Red selects ith strategy and Blue selects jth strategy, one has to describe a payoff function.

In this analysis, the payoff function has been chosen to be the state of 'balance of force', i.e., the difference between I.C.E. of the two forces. Payoff function is the sum of the differences between the I.C.E. of both forces at all points of attack. This payoff function is altered by the following factors:-

- (a) Vulnerability of a particular sector.
- (b) Attack ratio.
- (c) Damaging capability of Blue's air force.

(a) Vulnerability factor (VINDEX): Blue's commander allots priorities to strategically vulnerable areas or grounds of tactical importance, according to their relative importance. Vulnerability factor (VINDEX) is found by the sum of priorities of all vulnerable areas within the circle of influence, which is taken to be 30 Kms., and scaling it by dividing it by $\min_j (\sum_i V_{ij})$ where $\sum_i V_{ij}$ denotes the VINDEX for attack point j.

Numerically:

$$VINDEX (j) = \frac{\sum_i V_{ij}}{\min_j (\sum_i V_{ij})}$$

where V_{ij} is the vulnerability index allotted to the strategically vulnerable areas

(b) Attack ratio It is defined as the intensity of Red's attack. It is evaluated by the following relation:

$$A.R(i) = \left(\frac{CR_i - CB_i}{CR_i} \right) / \min_i \left(\frac{CR_i - CB_i}{CR_i} \right)$$

where CR_i = I.C.E of Red force for point of attack i
 CB_i = I.C.E of Blue force for point of attack i

(c) Damaging capability of Blue's air force (DAM) This factor is dependant on the time spent by Blue's aircrafts over target area. It is evaluated by finding the total possible time which aircrafts from all air-bases can spend over the target area. This is then scaled by dividing it by minimum time spent over the target areas.

$$DAM(i) = \sum_{i=1}^3 (T_i) / \min_i \left(\sum_{i=1}^3 T_i \right)$$

The elements of game matrix are evaluated by considering the overall effect at all points of attack, i.e., the sum of effects at all points of attack is taken. For example, the a_{12} element of game matrix, refers to the situation where Red's main thrust is at the 1st point of attack and Blue's aircrafts give support at the 2nd point of attack.

Numerically:

$$a_{12} = ATT(1).VINDEX(1).[CE(1)-CO(1)] + \frac{[CE(2)-CO(2)]}{DAM(2)} + [CE(3)-CO(3)]$$

where $ATT(1)$ is the attack ratio at I^{st} point i.e. it denotes the intensity with which Red can attack at I^{st} point ---

$VINDEX(1)$ denotes the relative vulnerability of I^{st} point as compared with other points.

$DAM(2)$ represents the relative damaging capability of Blue's aircrafts at 2^{nd} point of attack $[CE(i)-CO(i)](i=1, \dots, 3)$, represents the difference between ICE's of Blue and Red.

In the above expression the state of balance of force at point 1 ($CE(1)-CO(1)$) is multiplied by $ATT(1)$ and $VINDEX(1)$ because the main thrust of Red is at I^{st} point of attack and these factors are directly proportional to the payoff available to Red. The state of balance at 2^{nd} point is affected by the Blue's aircrafts as the Blue gives airsupport at second point. Therefore, the state of balance ($CE(2)-CO(2)$) is divided by $DAM(2)$, which is the damaging capability of Blue's aircraft at 2^{nd} point of attack. The state of balance at third point is, however, unaffected by any of the factors.

In this manner all elements of the game matrix are evaluated.

3.12 Evaluation of priorities:

Once the game matrices for troops, armour and artillery are solved correct deductions from the solutions

are required to be made. The optimal strategies found in each solutions are converted into their percentages, for example if the optimal strategy for troops is $[0.6 \ 0.3 \ 0.1]$, it is converted into its percentage i.e. (60 30 10).

For each point of attack the converted optimal strategies for troops, armour and artillery are added, and whichever point is the highest is allotted priority one. This allotment alongwith display of relative factors namely VINDEX, DAM, ATT and payoff matrices can help the commander in his decision making.

CHAPTER IV

DEVELOPMENT OF ANALYSIS

4.1 Development of Simulation Model

The first step in analysis is to develop a suitable scheme for the representation of the area of battle operations in a computer. The following scheme is used in the present write.

Any point on the ground can be represented by an eight figure grid reference. In such a system, any two adjacent points represent a distance of 100 met. on the ground. This resolution is considered adequate for the purpose of analysis of combat situation involving a Corps frontage which can be anything between 100 to 200 Kms.

The grid reference of a point [See fig.(4.1)] is given by its northings followed by eastings. For example grid reference of point X is

56122614

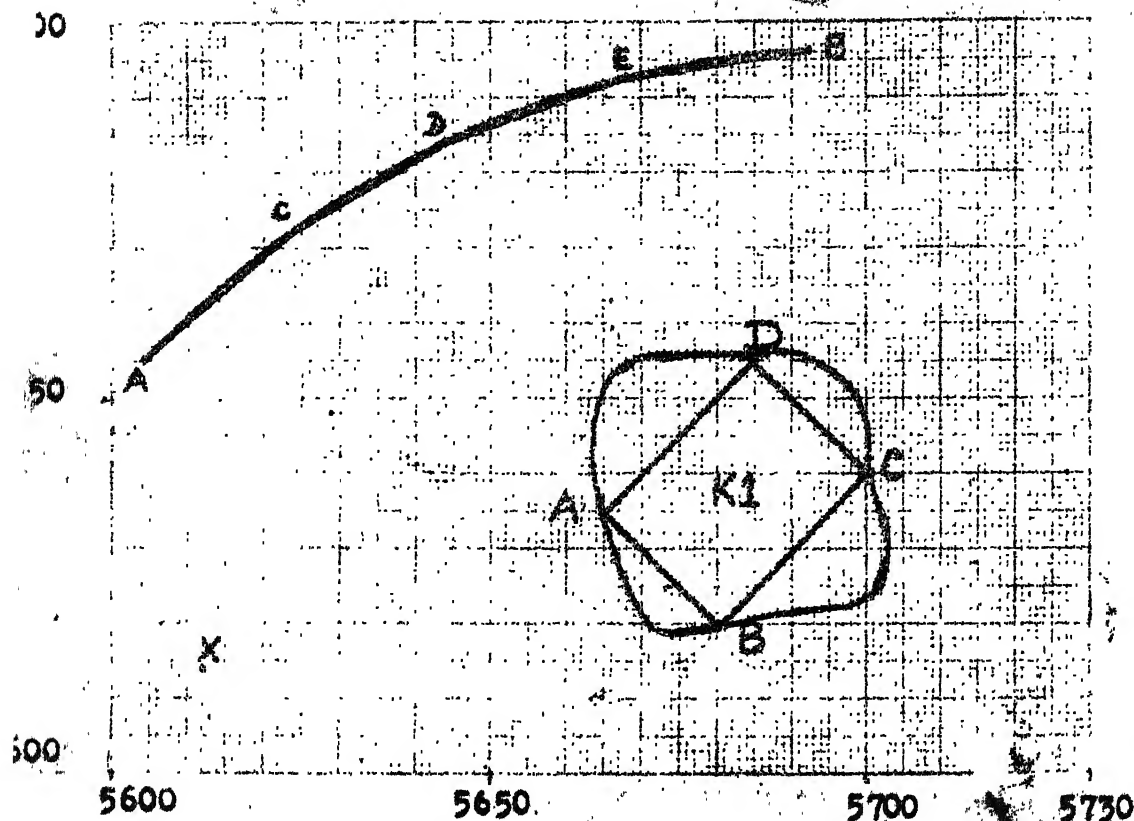
Northing of point X is 5612

and easting is 2614.

4.2 Representation of Terrain features

The hypothetical map was converted into straight line segments by approximating all curves by straight lines. [See Fig.(4.1)].

REPRESENTATION OF TERRAIN FEATURES



In the above fig., bottom right represents a figure of a particular type of terrain having terrain factor K1. This figure is approximated by number of parallelograms drawn inside it. One such parallelogram is shown as A B C D.

Grid references of A,B,C,D are 56652635, 56802620, 57002640, 56852655 respectively.

This parallelogram would be represented by the following format:

56652635 b 56802620 b 57002640 b 56852655 b K1

Figure (4.1)

AB represents a road curve and is approximated by straight line segments AC, CD, DE and EB. The number of intermediate points depend upon the accuracy desired and memory available. In this manner, all terrain features like roads, tracks rivers, canals etc. are first approximated by straight line segments. Various terrain features and format used for storing their data are given below:-

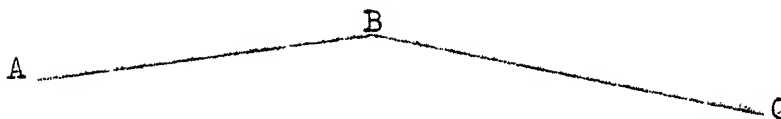
(a) Roads and tracks: After carrying out the straight line approximations node numbers are allotted to all points for the purpose of identification. A file is created to store the data and the format used is given below:

N1 GR1 bb N2 GR2

where N1 is node number of starting point
 GR1 is grid reference of starting point
 N2 is node number of end point
 GR2 is grid reference of end point
 b denotes blanks.

Starting point of a road branch is one whose northings or x co-ordinate is less than those of (end point, [See Fig. (4.2) for example]

(b) Canals and rivers. A separate file is used for storing information about canals and rivers.

REPRESENTATION OF ROADS AND TRACKS

AB and BC are two road branches

Grid reference of A = 56002600

Grid reference of B = 56402620

Grid reference of C = 56852590

Node numbers of A,B,C are 100, 104, 107 respectively

Format used to represent above road branches

10056002600 bb 10456402620

10456402620 bb 10756852590

Figure (4.2)

Format Format used is:

GR1 b b GR2

where GR1 is grid reference of starting point
 GR2 is grid reference of end point

No node numbers are required in this case as there is no requirement to travel along the canal or river but only crossings would have to be attempted. Here also the definition of starting point and end point are same as in case of roads and tracks.

(c) Different types of terrains The ground is classified into various types depending on the effect on mobility:

- (i) Marshy land
- (ii) broken ground
- (iii) cultivated fields
- (iv) flat ground

The ground is represented by number of parallelograms which approximates the given area. Given in Fig.(4.1) is an example of how the approximation is carried out:

The area is represented by giving grid references of points A,B,C,D (in this order) followed by the terrain factor. Format used is given below:

GR(A) b GR(B) b GR(C) b GR(D) b K1

where $GR(A)$, $GR(B)$ --- is grid reference of point A,B---.

and K_1 is the terrain factor which gives the effect of terrain on mobility. It is used as a multiplier in distance calculations.

(d) Bridges and Vital points These are considered to be point objects and they are stored in their files as grid references only.

4.3 Representation of Deployments and boundaries

This representation is flexible in nature and data stored is changed as the battle situation changes. Data structure used is multi dimensional arrays which facilitates insertion of entries and their deletion.

The boundry or line of actual control changes with the battle situation. It is approximated by straight line segments and stored in a separate file in the same format as used in the case of canals and rivers.

Deployments Various fighting units i.e. infantry, armour or artillery units are represented by their status and their grid references. The information about Red and Blue forces are stored in the same file. Three files pertaining to troops, armour and artillery store this information. Formats used for troops, armour and artillery are listed below:-

(a) Troops: Format used for storing information about infantry units is:-

Status GR

where GR denotes grid reference of the unit

Status of unit is a three digit number
in which:

- (i) the first digit gives type of force: 1 for Red force and 2 for Blue force
- (ii) the second digit denotes strength of field unit. for example: 500 troops are represented by number 5, and
- (iii) the third digit denotes morale of the troops.

(b) Armour: As in the case of troops the information about armour units is given by its grid reference and its status. Format used is

GR bb status

Here status, indicated by a three digits number
in which:

- (i) The first digit: which force does the tank unit belong to
- (ii) the second digit: which denotes the type of tanks held by the armour unit, and
- (iii) the third digit: gives the strength of tanks in terms of troops of tank.

(c) Artillery Format used is the same as in case of armour. Status of artillery unit is again

indicated by three digit number in which:

- (i) the first digit indicates the force
- (ii) the second digit denotes the type of gun held by the field unit, and
- (iii) the third digit gives the number of guns deployed by the unit.

4.4 Choice of data structure

As data representation is in matrix form a number of multi-dimensional arrays have been used. Arrays have been used for storing data about troop, armour and artillery units. These can be updated as and when status of units changes due to battle situation. This type of data structure facilitates insertion and deletion of entries. Different files have been used in order to have easy access to particular type of data.

4.5 Combat Effectiveness Calculations

Troops A set of subroutines, namely TROOPS, ELMIN, ROUTES, PATHS have been developed for calculating combat effectiveness for troops. TROOPS subroutine searches for all troop units of both Blue and Red forces within a circle of 20 Kms. from point of attack. Steps of subroutine TROOPS and flow chart are given in appendix (B-1)..

ELMIN subroutine is used for eliminating all troops which are deployed along the boundry line separating the two forces. All such units are deployed to contain the enemy and

as such cannot be pulled out to be used elsewhere. Steps of subroutine ELMIN and flow chart are given in appendix (B-2).

Distance Calculations Subroutine ROUTES and PATHS calculate the minimum distance between any two points.

A road map is like a labelled graph. The distance calculation is a typical shortest distance problem of a travelling salesman. The algorithm used is called the Robert and Ferland (RF) algorithm which is a generalization of the Roy-Warshall algorithm.

Subroutine ROUTES searches for all road branches in the circle of influence and allots them dummy node numbers. It then generates XX matrix, which is weighted distance matrix for subroutine PATHS.

Subroutine PATHS [ATB-5] calculates minimum distance between any two nodes. For finding distance of one field unit from its location to centre of influence, the nearest nodes to it and the centre are evaluated and minimum distance between these nodes is found from matrix XSTAR which is output of subroutine PATHS. Algorithms and flow charts are given in appendix (B-3).

I.C.E. is then found by following relation:

$$CE = [N \times R \times M.F. \times (1 - \frac{D}{KI})]$$

where N = Number of combatants

R = rate of fire

$M.F.$ = morale factor

D = distance between unit and the centre of circle of influence.

$K1$ = maximum distance at which combat-effectiveness is felt. It is equal to 20 Kms.

ARMOUR

Subroutine ARMOUR searches for all armour units of Red and Blue forces within a circle of 30 Kms. Next for each armour unit, shortest distance from its position to centre is evaluated. However, due to obstacles like canals and rivers straight line paths may not be possible. Subroutine CHECK checks for any obstacles in straight line paths and in case of crossings it calls subroutine NBRID to search for the nearest bridge along the canal. In this manner the route to the centre is established. Steps involved in CHECK and NBRID and their flow chart are given in appendix (B-4).

Effect of terrain on mobility along the route is evaluated by subroutine TERRAIN. Along the route, the total distance the tank would have to move along different classes of terrain is evaluated and multiplied by respective terrain factors. The sum of this distance would give the total distance to be traversed. Steps involved in TERRAIN and the flow chart are attached in appendix (B-5).

Combat effectiveness of Armour units

$$= [N \times R \times LA \times (1 - \frac{D}{K2})]$$

where N = strength of tanks

R = rate of fire of shells (no. of rounds/min)

LA = lethal area of shells

D = distance to be traversed.

K2 = maximum distance at which effect of combat-effectiveness is felt.

Artillery

Subroutine GUNS searches for all artillery units of Red and Blue forces within circle of influence. Next for each artillery units, subroute TROOPS is called to determine the number of enemy troops which can be brought under fire with type of gun held by the unit. The ICE of each unit is calculated and summed to give the total ICE of artillery in that sector. Steps of subroute GUNS and flow chart are given in appendix (B-6).

Numerically

I.C.E. of artillery

$$= [N \cdot R \cdot LA \cdot NET]$$

where N is number of guns in the unit

R is rate of fire of guns

LA is lethal area of shells

NET is number of enemy troops which can be brought under fire.

CHAPTER V

DESCRIPTION AND DEVELOPMENT OF GAME

5.1 Development of Game Matrix

To develop the elements of game matrix, a pay-off function has to be selected. In this analysis pay-off function is taken to be the state of balance of the forces. It is given by the difference of the combat-effectiveness indices of the two forces at the point of attack. This value of pay off function is affected by the following factors:

(a) Vulnerability index factor (VINDEX): Subroutine VALUE evaluates the number of vital or strategic points around each point of attack. Steps and flow chart of VALUE is attached in appendix (B-7).

$$\text{VINDEX}(j) = \frac{\sum_i V_{ij}}{\min_j (\sum_i V_{ij})}$$

where $j = 1 \text{ -- } 3$ (where j gives the points of attack).

(b) Attack ratio factor (ATT) It is evaluated after I.C.E.s of Red and Blue forces have been determined. It indicates the intensity with which Red is capable of attacking at different points of attack. It is evaluated using the relation:

$$\text{ATT}(i) = \left(\frac{\text{CE}(i) - \text{CO}(i)}{\text{CE}(i)} \right) \min_i \left(\frac{\text{CE}(i) - \text{CO}(i)}{\text{CE}(i)} \right)$$

where $i = 1 \text{ --- } 3$

where CE and CO are I.C.E's of Red and Blue force respectively.

(c) Factor due to damaging capability of Blue's air-force (DAM) Subroutine AIRCAP (flow chart attached in appendix (B-8) is called to evaluate the total possible time aircrafts from various bases can spend over each point of attack. these values are then scaled by dividing by the minimum value.

Pay-off of Red is directly proportional to first two factors and inversely proportional to the third.

The elements of game matrix A are defined by

$$a_{ij} \begin{cases} i=1..3 \\ j=1..3 \end{cases} = \sum_{k=1}^3 \frac{ATT(i) \cdot VINDEX(i) \cdot (CE(k) - CO(k))}{DAM(j)}$$

where if $j \neq k$ $DAM(j) = 1$

and if $i \neq k$ $ATT(i) = 1$
 $VINDEX(i) = 1$

5.2 Solution of Game

Brown's Algorithm

Brown's algorithm [BEG-6] is one of the most practical methods of solving games that are larger than $2 \times n$ or $m \times 2$. It assumes that the past is best guide to the future. That is player I plays some row, say row 1, on the first play of the game, then player II plays the column that would minimize the pay-off. Player I then examines

the column player II plays, and plays the row corresponding to the largest pay-off. Player II sums element by element the rows I has played, and plays the column corresponding to the smallest sum element. Player I then sums element by element the columns player II has played so far, and plays the row corresponding to the largest sum element. This iterative process is continued until a decision to stop is made. The proportion of the time column j is played is an approximation of y_j^* for $j = 1, 2, \dots, n$. Likewise, the proportion of the time row i is played is an approximation of x_i^* for $i = 1, 2, \dots, m$.

For example consider a 3×3 game whose matrix is:

$$\begin{bmatrix} 1 & -2 & 3 \\ 1 & 3 & -2 \\ 4 & 2 & 1 \end{bmatrix}$$

Suppose player I starts by playing row 2. The minimum element in row 2 is -2 , so player II plays column 3. The maximum element in column 3 is 3 and is found in first row, so player I plays row 1. The sum of two rows played by player I is

$$[1 \ 3 \ -2] + [1 \ -2 \ 3] = [2 \ 1 \ 1]$$

Player II arbitrarily selects column 2 to play next since minimum sum is in column 2. Player I now sums two columns player II has played and finds that the largest

sum is in row 3 namely:

$$\begin{bmatrix} 3 \\ -2 \\ 1 \end{bmatrix} + \begin{bmatrix} -2 \\ 3 \\ 2 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 3 \end{bmatrix}$$

Therefore he plays row 3 next. This process is repeated again and again. The results of first 10 iterations are given in Fig. (5.1). The approximate optimal strategies for player I and II are:

$$x \approx \begin{bmatrix} 2/10 \\ 0 \\ 8/10 \end{bmatrix} \quad y \approx \begin{bmatrix} 0 & 4/10 & 6/10 \end{bmatrix}$$

Actual optimal strategies for the given example are

$$x = \begin{bmatrix} 1/6 \\ 0 \\ 5/6 \end{bmatrix} \quad y = \begin{bmatrix} 0 & 1/3 & 2/3 \end{bmatrix}$$

Hence we see that approximate solution is quite good after just 10 iterations.

5.3 Steps of Brown's algorithm

Steps of the algorithm are:

1. Red selects a row to play, and Blue then plays the column corresponding to the minimum element in the row.
2. Red then selects the row to play that corresponds to

Play of game

			1	2	3	4	5	6	7	8	9	10	
1	-2	3	③	1	4	⑦	5	3	1	4	7	10	2/10
1	3	-2	-2	1	-1	-3	0	3	6	4	2	0	0
4	2	1	1	③	④	5	⑦	⑨	⑪	⑫	⑬	⑭	8/10

1 3 ②

2 ① 1

6 3 ②

10 5 ③

11 ③ 6

15 ⑤ 7

19 ⑦ 8

23 9 ⑨

27 11 ⑩

31 13 ⑪

Sum of columns player II
has played to date

Sum of the rows
player I has played
to date

0 4/10 6/10

Fig.(5.1): Example of Brown's algorithm.

the maximum element in the column selected by Blue in Step 1.

3. Blue sums the rows Red has played thus far, and plays the column corresponding to a minimum sum element.

4. Red sums the columns Blue has played thus far, and plays row corresponding to a maximum sum element. If the desired number of iterations is satisfied go to step 5; otherwise, return to step 3.

5. Optimal strategy of Blue is given by proportion of the time Red has played row i .

In the analysis the number of iteration done was restricted to 20.

5.4 Deduction of solutions

The optimal strategies of Blue in respect of troops, armour and artillery game matrices are converted into percentages. These are then added for each point of attack and highest of them gives the place where the air-support is to be allotted.

The allotment of priority alongwith relative factors like VINDEX, DAM, ATT and payoff matrices are displayed on a terminal in a simple form. Commander can thus make his decision based on these results.

CHAPTER VI

RESULTS AND CONCLUSION

6.1 RESULTS

Hypothetical situations involving three air-support demands pertaining to points A (GR-66602579), B (GR-59002760) and C (GR-62302880) were analysed. Three situations of extreme nature were depicted such that different points warranted air-support in each situation. These inferences were based on deductions of normal military appreciations of the situation. The following cases have been discussed:-

- (a) Case '1': The data was such that points 'A' warranted an air-strike. The results of analysis and form in which it is presented to commander is given in appendix [A-1].

The presented form helps the commander to get an intuitive idea of relative importances of various factors and thus, aid him in his decision making. The results of analysis developed agrees with the one reckoned from military appreciation.

- (b) Case '2': In this case the situation was so projected such that point 'B' needed air-support. The other two points were given less importance in comparison to point 'B'.

Results of this analysis are given in appendix [A-2]. Results in this case are in accordance

with the one obtained from manual appreciation.

- (c) Case '3': In the last situation the posture was one in which point 'C' (GR-62302880) needed air support. Analysis of this situation and its results were compatible with the military appreciation of situation. Results are given in appendix ([A-3]).

The above three situation were extreme situations and the results compared favourably with the expected results. However, it was not feasible to check results in not so extreme cases.

6.2 CONCLUSION

The above analysis is done in a elementary form. However, inferences drawn from this study indicate that the form of logic used is an appropriate one and can be used in different situations. One such situation could be to detect weak spots in deployments. Such form of analysis could also be used to test different defensive postures and plans.

Combat-effectiveness values would differ with different form of operation. A further study of this factor can greatly increase the suitability of such form of analysis.

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CASE '1'

ANALYSIS OF AIR-SUPPORT DEMANDS

=====

ALLOT PRIORITY 1 AT GRID REFERENCE ***55602579***

=====

DETAILS OF VARIOUS FACTORS

	GR-55602579 -----	GR-59002760 -----	GR-62302880 -----
VINDEX=	1.5000	1.3500	1.0000
DAM=	1.0818	1.0843	1.0000
ATT=			
TROOPS	1.0000	2.2436	2.6699
ARMOUR	1.4056	1.0000	1.2170
ARTILLERY	2.6129	1.0000	6.2308

PAYOFF MATRICES :

TROOPS

969.2026	960.5841	988.8967
1627.8869	1555.2532	1641.0153
1497.2991	1482.1148	1510.4220

ARMOUR

72604.9090	75332.7360	76418.3570
52994.2070	53337.2610	54802.8880
50719.3180	51442.3780	52527.9760

ARTILLERY

6440.8936	6825.5794	6841.1170
2867.8823	2949.0080	2969.9880
9859.4209	9945.9890	9961.4637

CASE "2"

ANALYSIS OF AER-SUPPORT DEMANDS

=====

AERO PRIORITY 1 AI GFD REFERENCE ***59002760***

=====

DETAILS OF VARIOUS FACTORS

	GR-55002579 -----	GP-59002760 -----	GR-62302880 -----
VOLUME=	1.5000	1.7000	1.0000
QAL=	1.0818	1.0843	1.0000
ATL=			
Troops	1.0000	4.8193	5.5862
Aer-Supp	1.1549	1.1597	1.0000
Artillery	1.0000	1.0743	1.2891

FOYOTR MATRICES :

TROOPS

930.5190	902.8093	938.8967
4235.4043	3945.2901	4240.9684
2567.2941	2536.7708	2572.8433

ARMOR

60100.4590	60919.3160	63233.8320
92636.8420	90082.2080	94645.5220
63912.0620	63406.8270	65721.3430

ARTILLERY

2750.4012	2818.3512	2864.9933
2779.3434	2770.5507	2855.7359
2500.4325	2530.1828	2576.8231

CASE '3'

ANALYSIS OF AIR-SUPPORT DEMANDS
=====ALLOT PRIORITY 1 AT GRID REFERENCE ***62302880***
=====

DETAILS OF VARIOUS FACTORS

	GR-55602579 -----	GR-59002760 -----	GR-62302880 -----
VINDEX=	1.0000	1.1333	1.3333
DAM=	1.0818	1.0843	1.0000
ATT=			
TROOPS	1.0000	3.0002	5.0110
ARMOUR	1.0000	1.1614	1.0983
ARTILLERY	3.3290	1.0000	5.2222

PAYOFF MATRICES :

TROOPS

1059.4071	1033.7841	1062.0941
3997.3586	3743.3156	4000.0457
7120.5640	7094.9470	7023.1710

ARMOUR

76682.1620	76176.3270	78490.7290
86095.6530	84857.9380	87904.2210
88201.8360	87696.0010	87600.3010

ARTILLERY

15213.8040	16218.6110	16241.9150
14139.5468	14313.5657	14339.9791
19112.5100	19289.6380	19012.8170

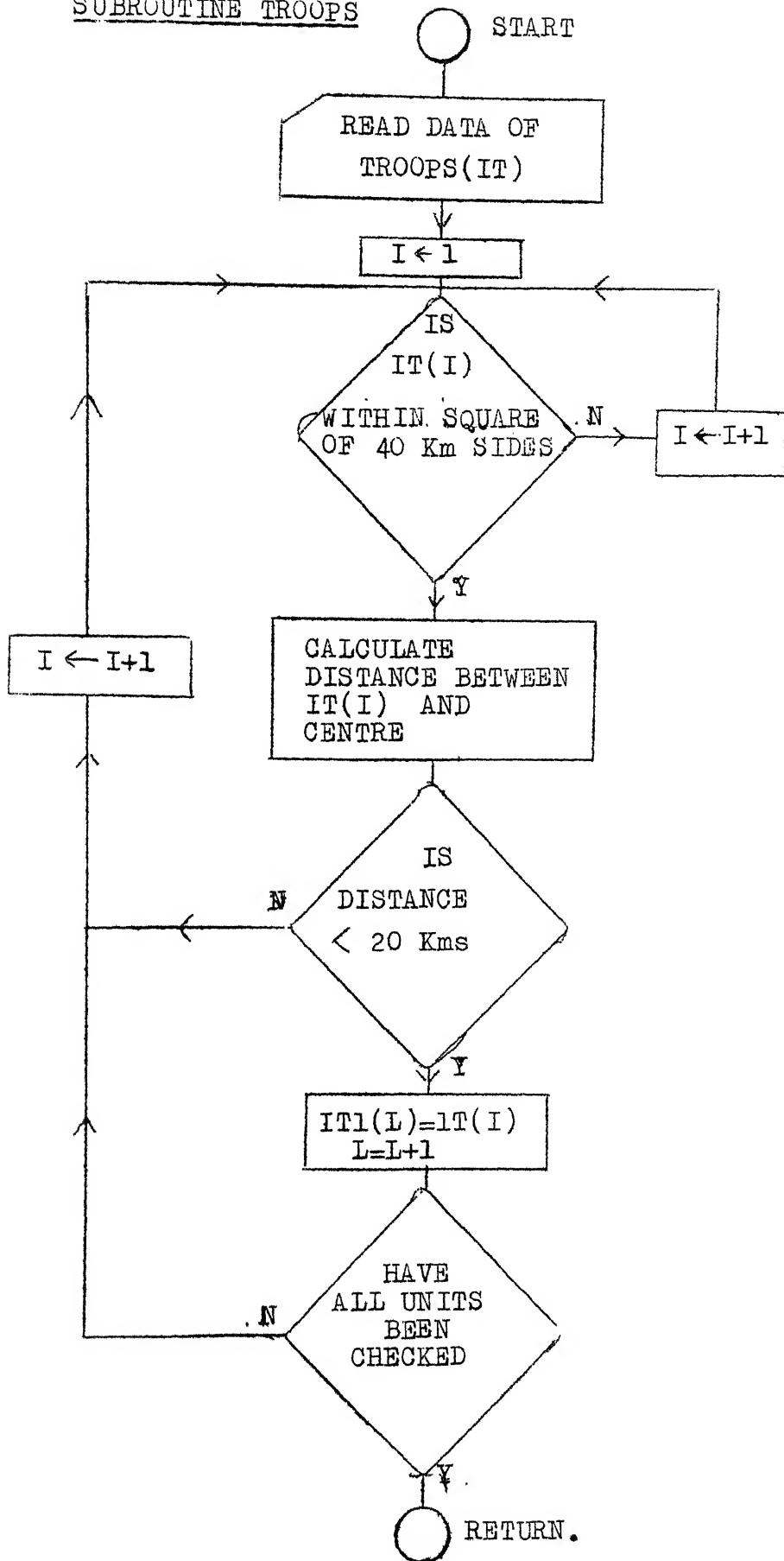
STEPS OF SUBROUTINE 'TROOPS'

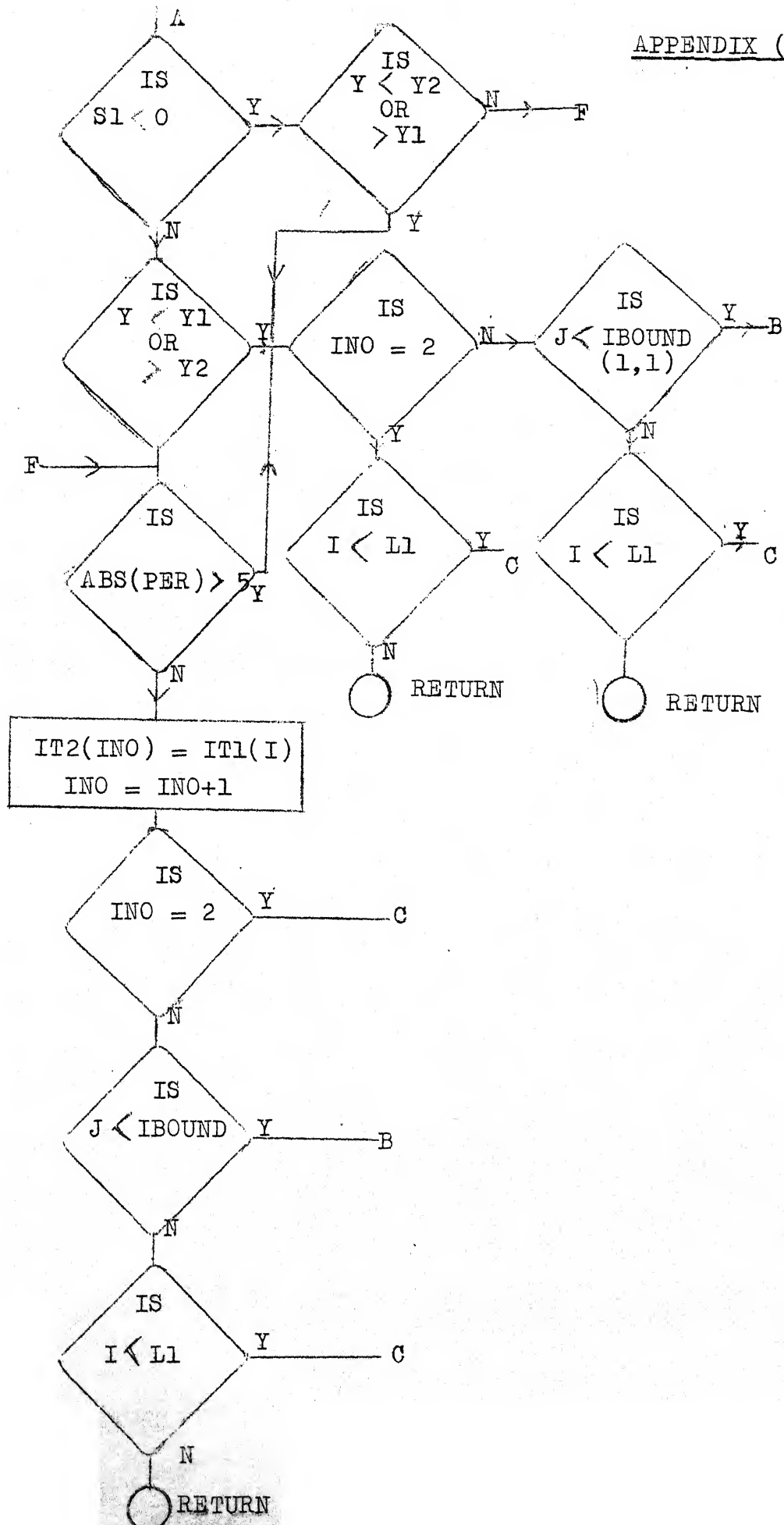
1. Read data of troops
2. Eliminate all those units, which lie outside a square of 40 Kms. sides with the point of attack lying at intersection of its diagonals.
3. All units within this square are checked if distance of unit to the point of attack is less than 20 Kms. or not. Eliminate if more than 20 Kms.

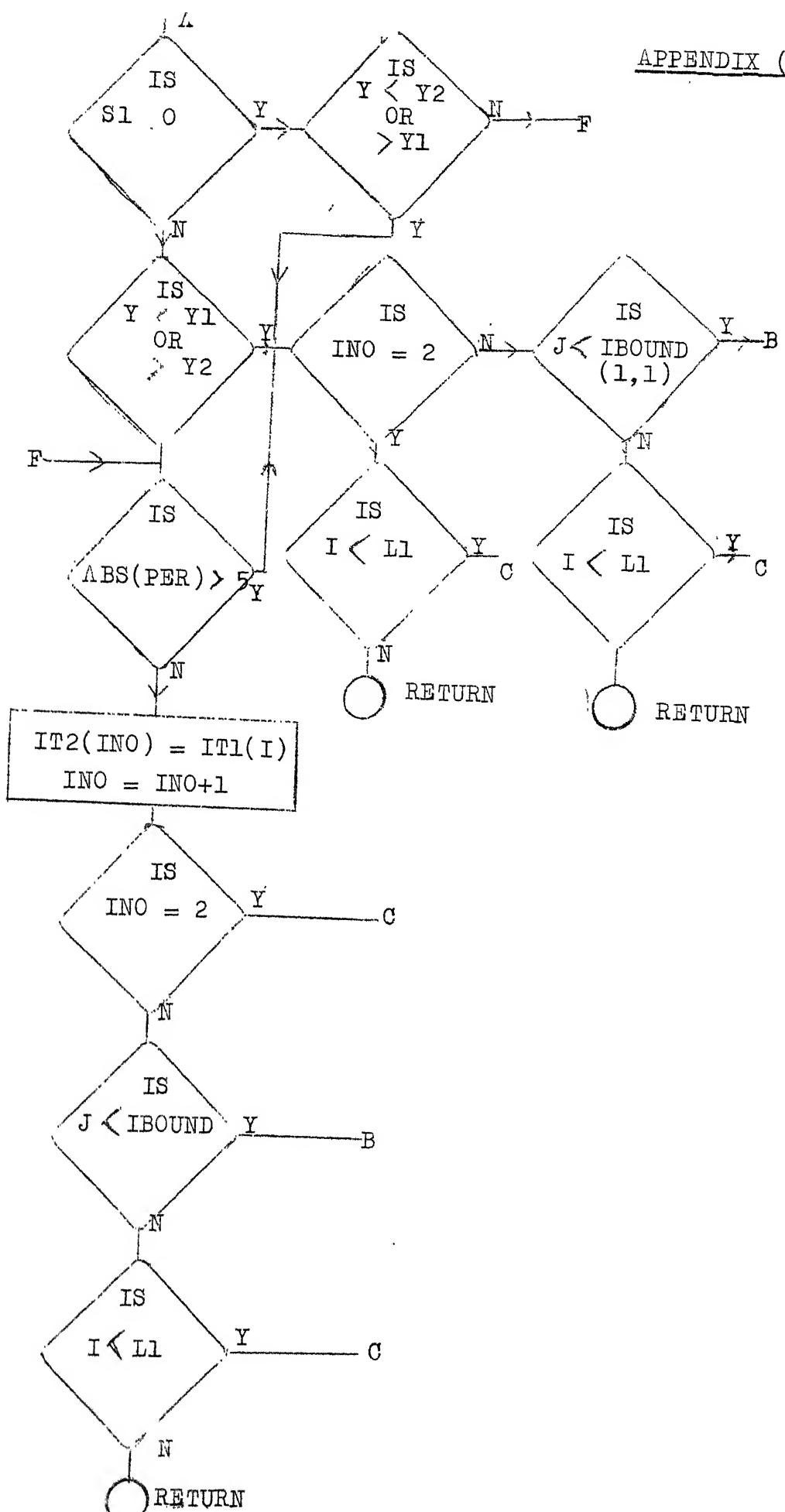
STEPS OF SUBROUTINE 'ELMIN')

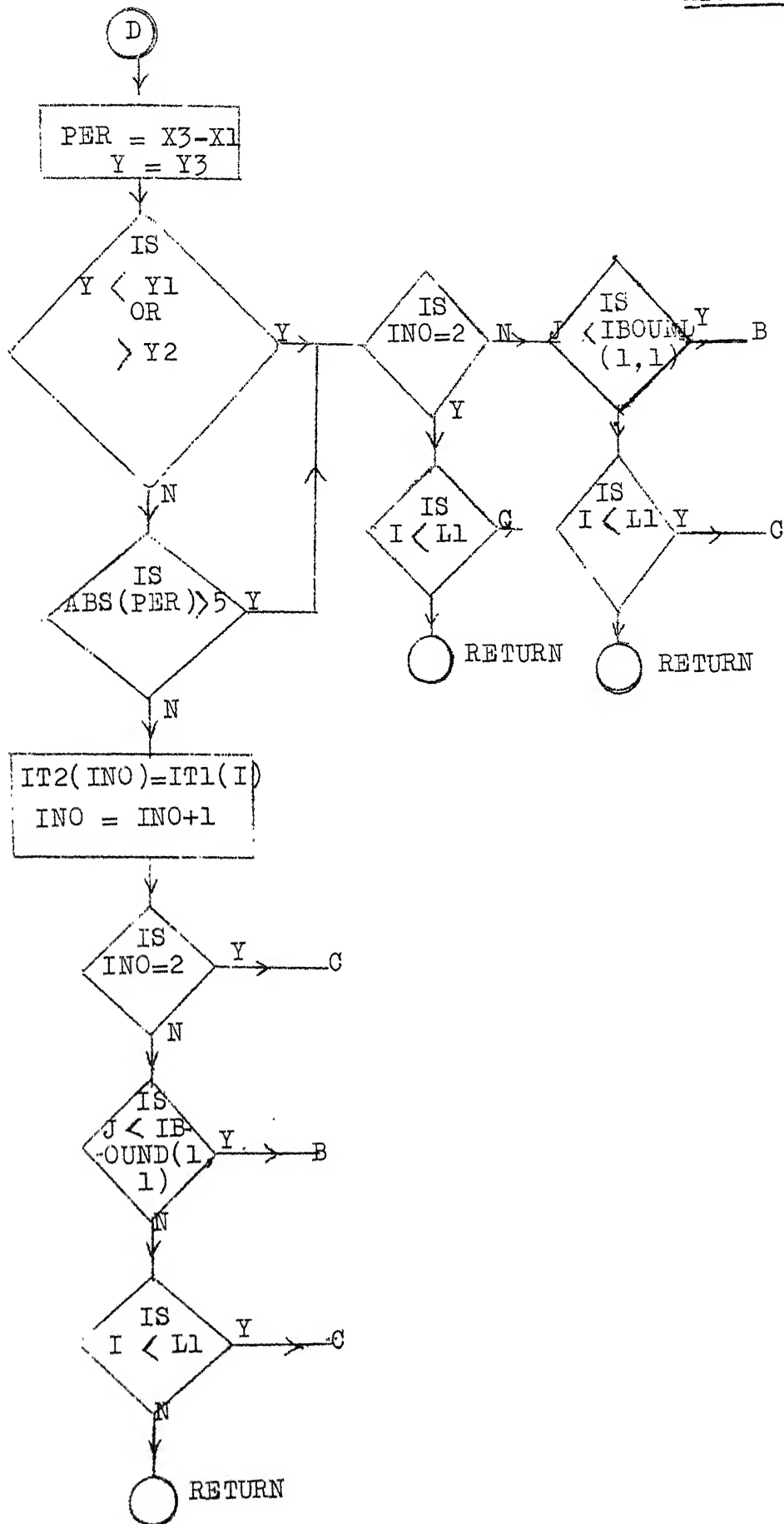
1. Read data of troops within 20 Kms. radius and boundary line.
2. Find perpendicular from location of unit to the straight line segments of boundary line.
3. Eliminate all those units where perpendicular is less than 5 i.e. the unit lies within 500 met. of boundary line.

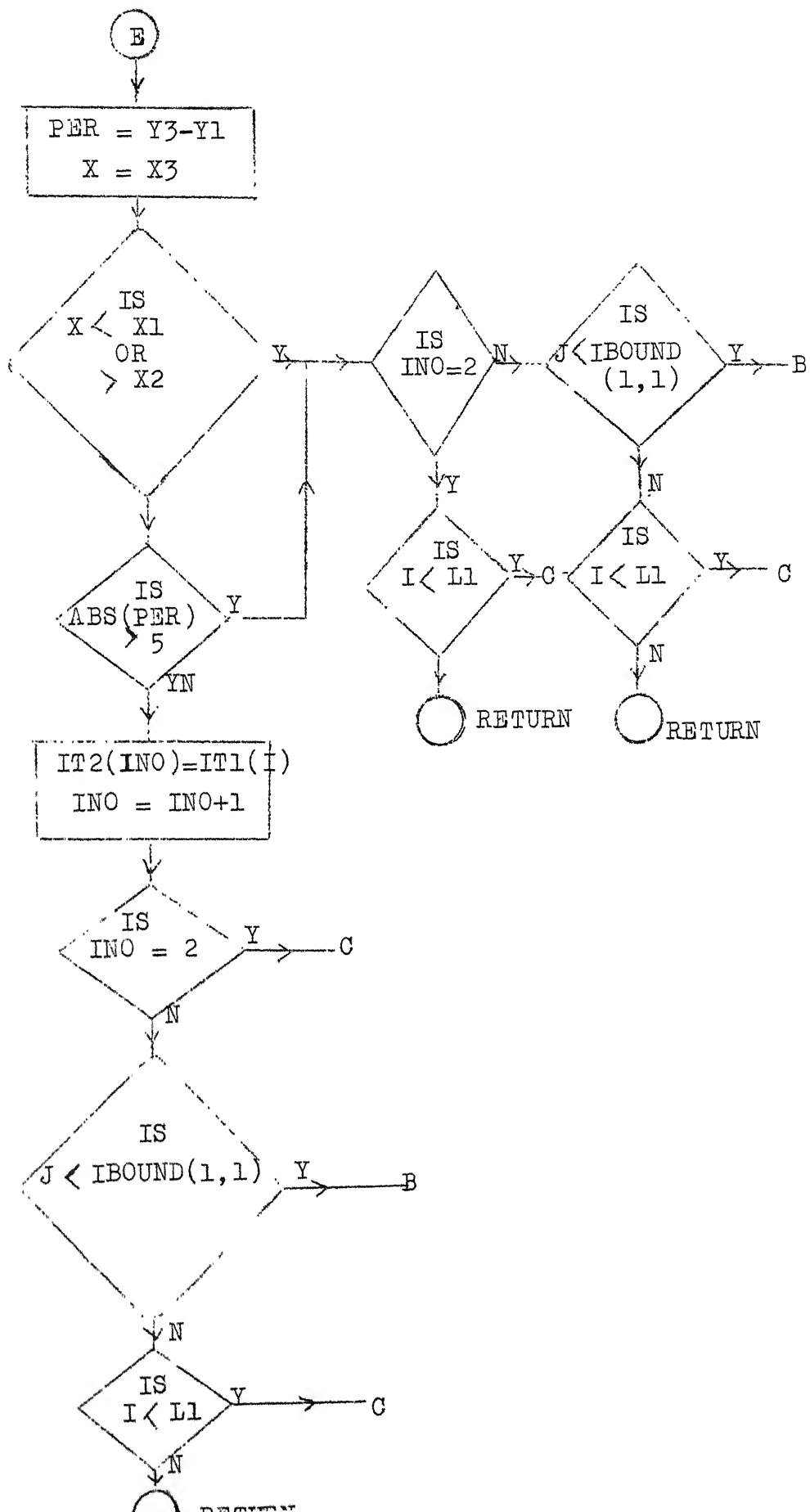
SUBROUTINE TROOPS

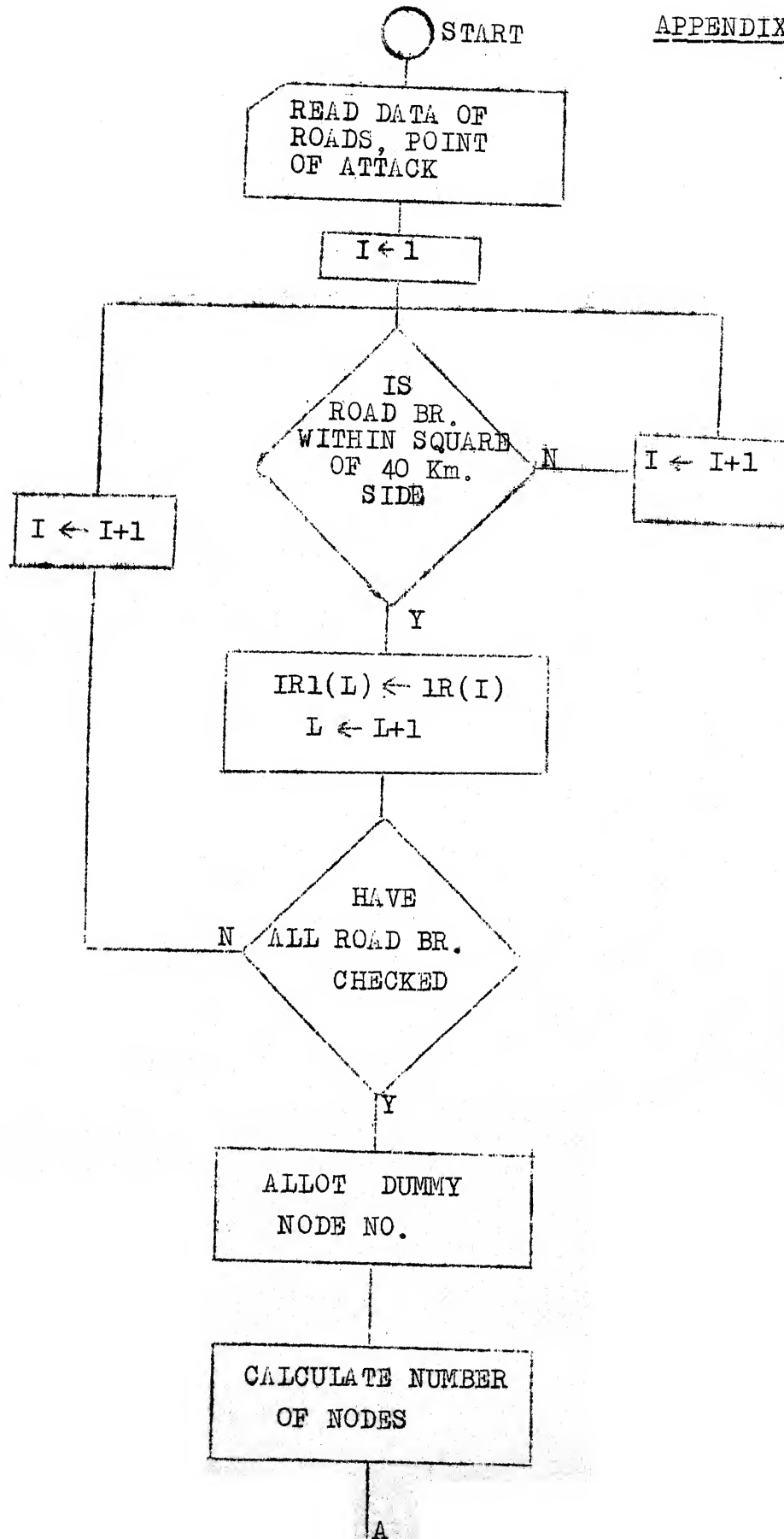


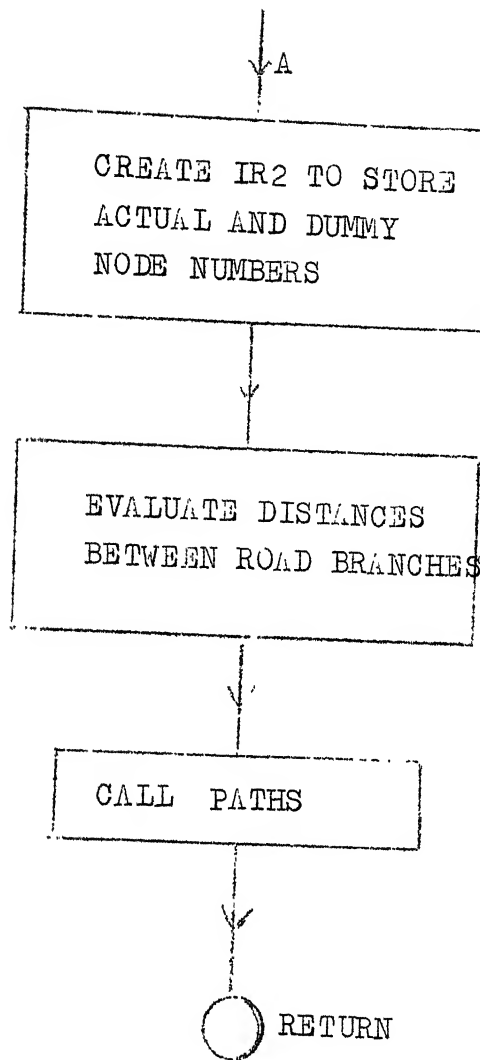












Steps involved in subroutine ARMOUR:

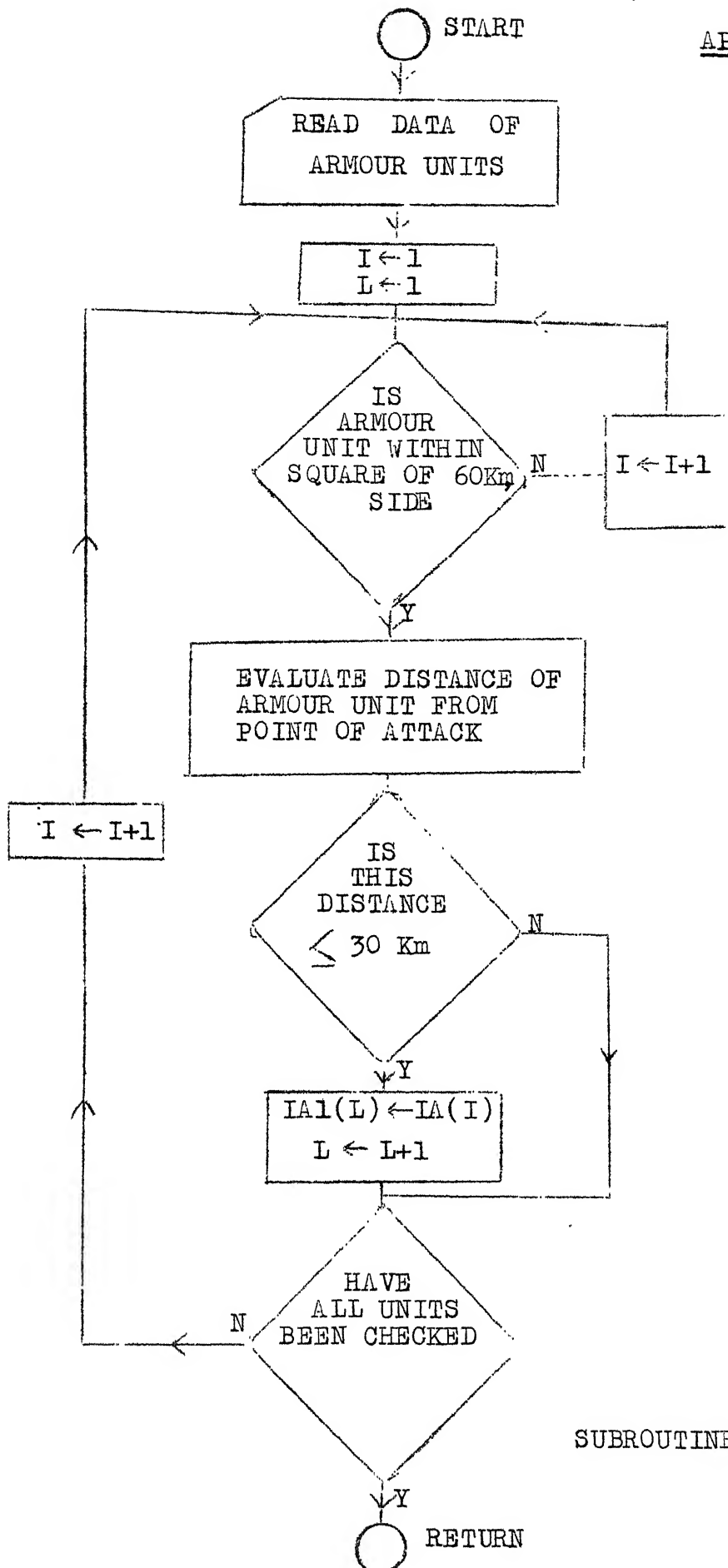
1. Read data of armour units and points of attack.
2. Eliminate all units which are outside the square of 60 Kms. sides with point of attack lying at intersection of its diagonals.
3. Calculate distance of units within this square and eliminate all those units whose distance from centre is greater than 30 Kms.

Steps involved in subroutine CHECK:

1. Read data of unit location and point of attack.
2. Check if there is any real intersection with canal branches.
3. Call subroutine NBRID if there is a crossing.

Steps of subroutine GUNS:

1. Read data of location of artillery units and points of attack.
2. Eliminate all those units which fall outside the square of 60 Kms. side with point of attack at intersection of its diagonals.
3. Calculate distance of each unit within the square from point of attack. Eliminate if this distance is greater than 30 Kms.



SUBROUTINE 'ARMOUR'

Steps of subroutine NBRID:

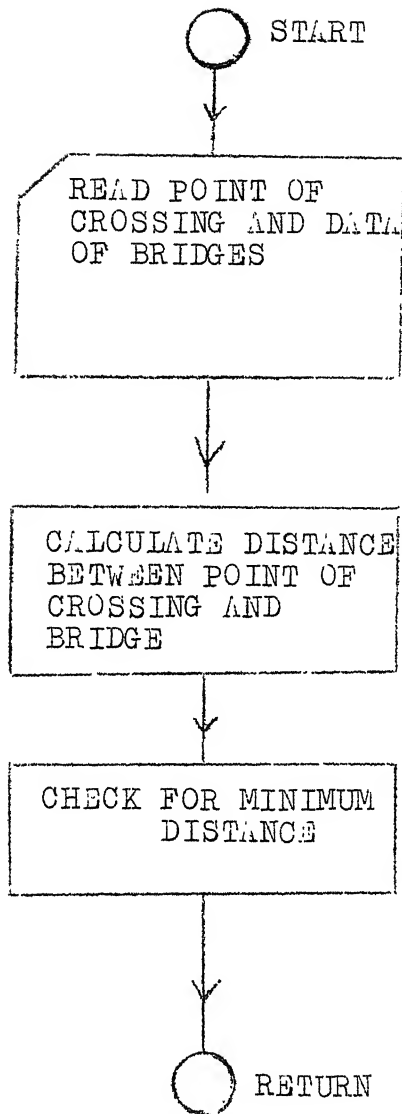
1. Read data of point of crossing and location of bridges.
2. Evaluate distances of point of crossing from each bridge.
Check for one with minimum distance.
3. Return nearest bridge as one with one with minimum distance.

APPENDIX (B-5)

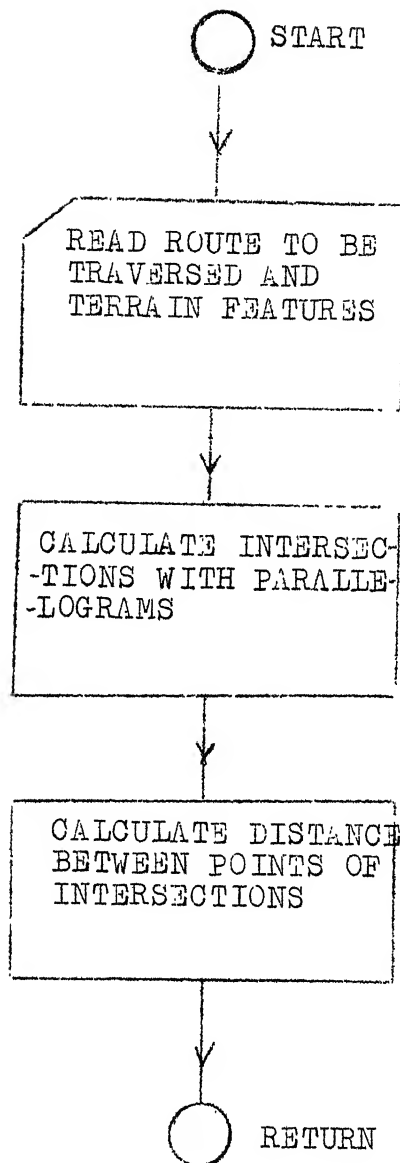
Steps involved in subroutine TERRAIN:

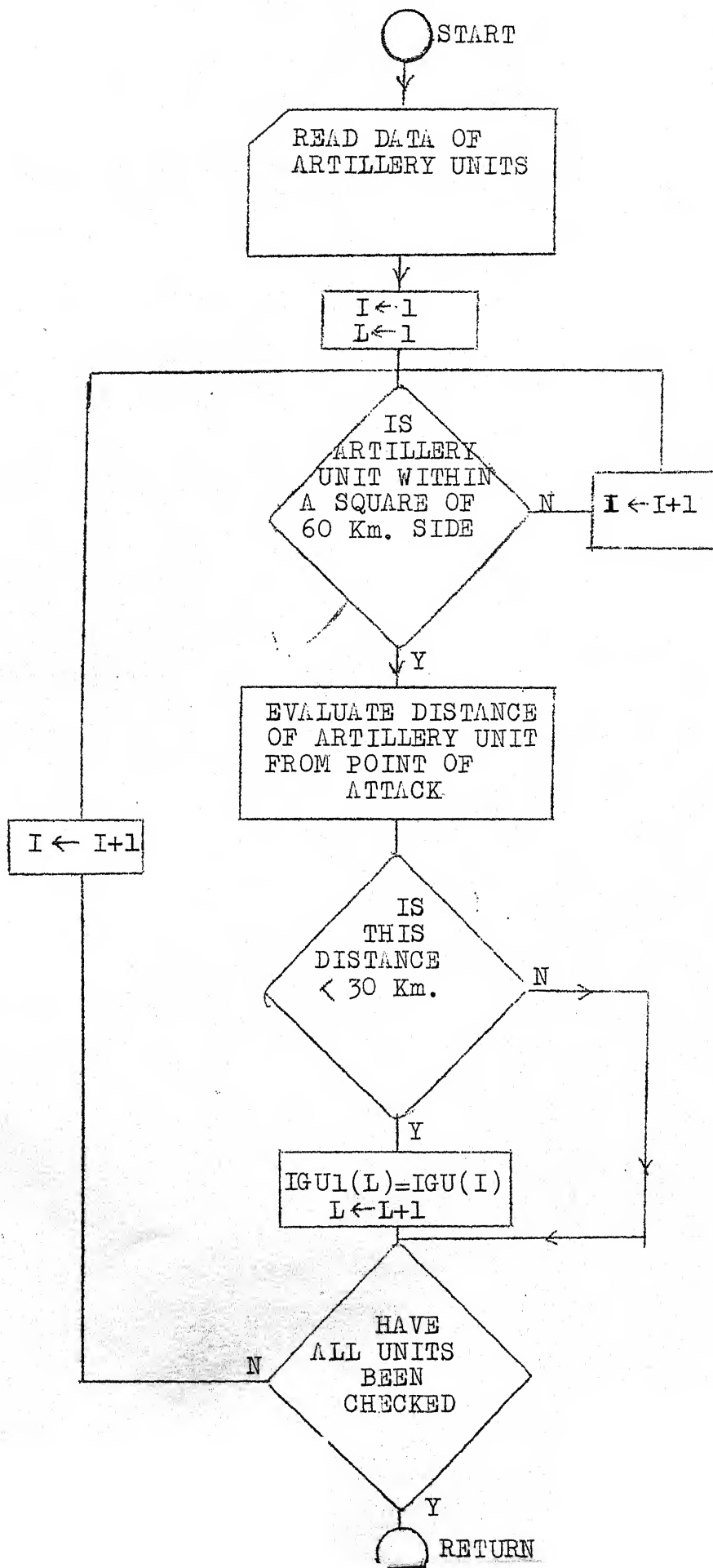
1. Read data of route to be traversed and different terrain areas.
2. Check for real intersections with parallelograms depicting different terrains. In case of intersection evaluate distance between points of intersection.
3. Return values of these distances alongwith terrain factors to the main program.

APPENDIX (B-4)



SUBROUTINE NBRID



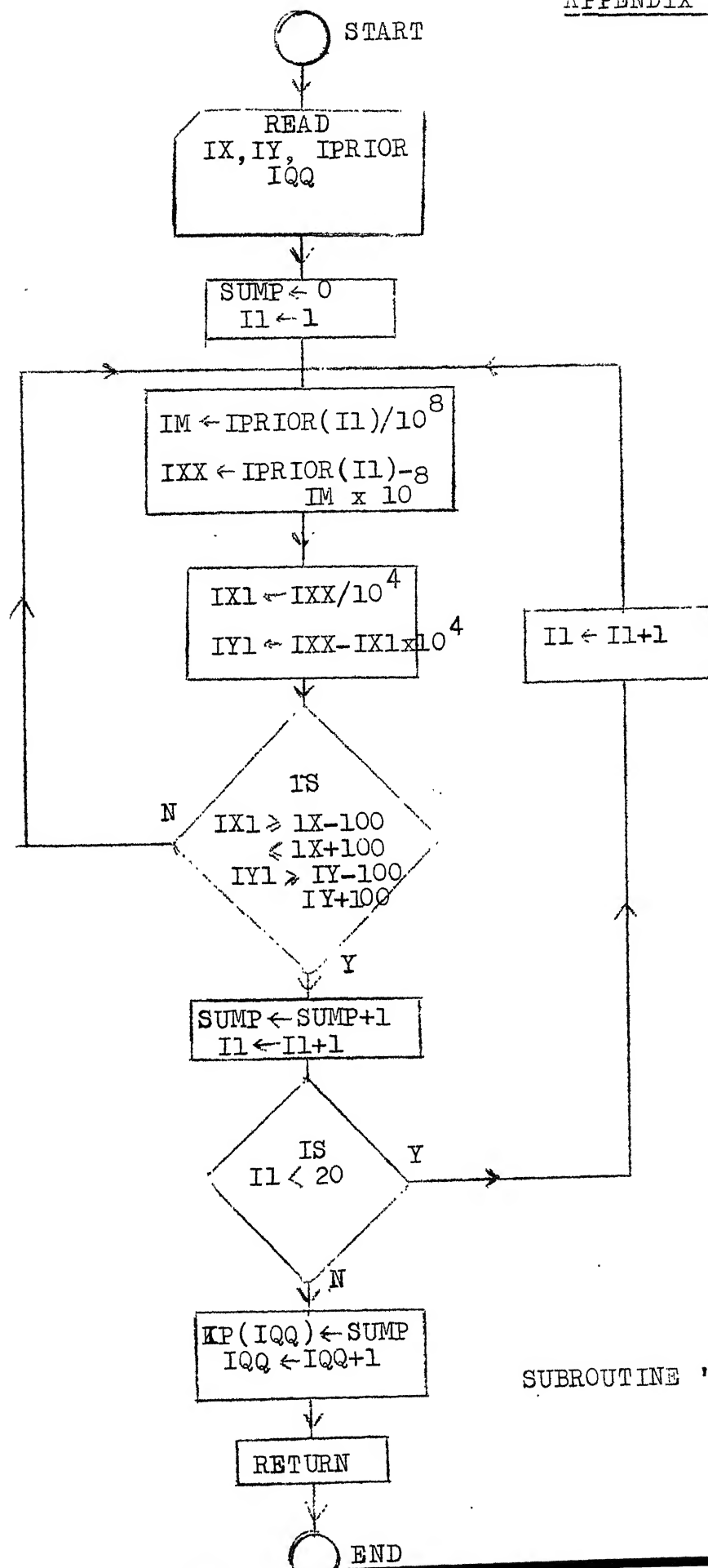


Steps in subroutine VALUE

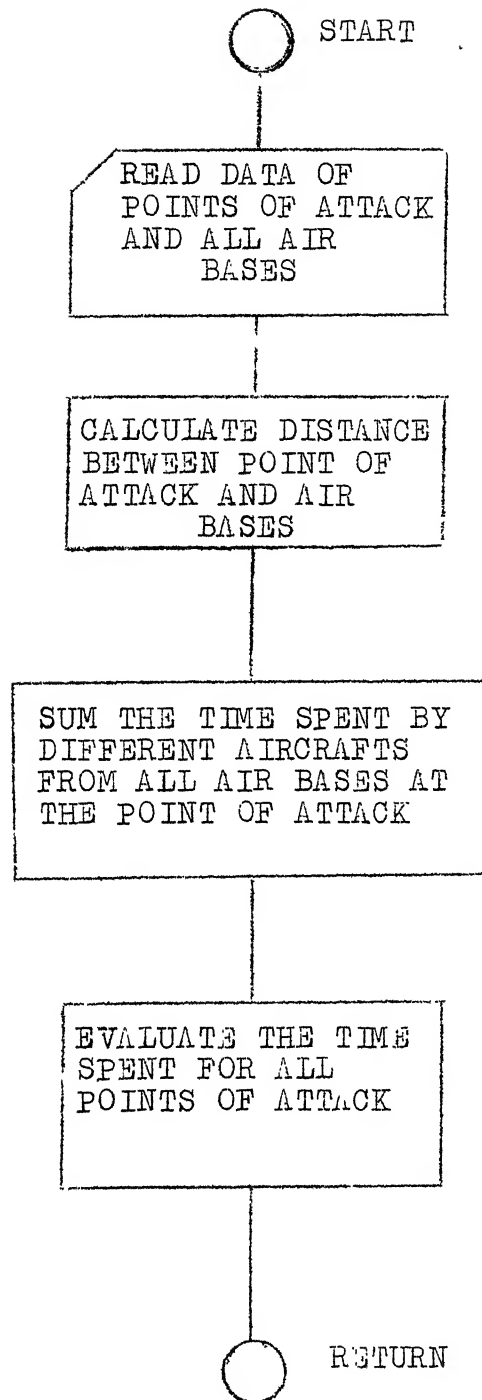
1. Read data of point of attack and vulnerable areas.
2. Eliminate all the vulnerable areas which are outside circle of influence.
3. Sum the vulnerability of all vulnerable areas within the circle and return it to main program.

Steps in subroutine AIRCAP

1. Read data of points of attack and air bases.
2. Check distance between point of attack and various air bases.
3. Evaluate time spent by various types of aircrafts from all bases at the point of attack.
4. Sum all the times spent by aircrafts at all points of attack.



SUBROUTINE 'VALUE'



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